

THE PALEONTOLOGY of the ZORRITOS FORMATION of the NORTH PERUVIAN OIL FIELDS

BY

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INTRODUCTION.

This paper presents the results of a detailed study of a collection of mollusks made by Dr. Joseph T. Singewald, Jr., from the Zorritos formation of northern Peru. Much of the value their evidence offers is due to the careful stratigraphic work done by Dr. van Holst, of the Hague, Holland, and Dr. Singewald, as a result of which the position of the subsidiary units of the Zorritos formation has been established, and a number of misconceptions concerning the relationships of the units to themselves and to the underlying Heath formation have been corrected.¹

PREVIOUS WORK.

The first account of fossils from the neighborhood of Zorritos was published in 1870 by Edward T. Nelson² as a graduating thesis in the Sheffield Scientific School of Yale University. This work was based on a collection of fossils

¹The author wishes to express his indebtedness to Professor Edward W. Berry under whose direction the work was done, and to Dr. J. T. Singewald, Jr., of the Johns Hopkins University; to Messrs. W. H. Dall, T. Wayland Vaughan, W. P. Woodring, and Miss Julia A. Gardner of the U. S. Geological Survey and U. S. National Museum; and to Professor Charles Schuchert of the Peabody Museum, and Dr. Henry A. Pilsbry of the Philadelphia Academy for the loan of material. The figures are the work of George S. Barkentin.

²On the Molluscan Fauna of the Later Tertiary of Peru, Trans. Conn. Acad., vol. 2, pp. 186-206, 1870.

made by Mr. E. P. Larkin and Professor F. H. Bradley. The fossils, which were collected in 1867, were labelled "Zorritos, Peru," and comparisons made during the present study indicate that most of them were probably from the three members of the Zorritos formation. Nelson mentioned 36 species of gastropods and 24 of pelecypods; of the gastropods he named 19 species, and of the pelecypods 8 species, mentioning the remainder as indeterminate.

Nelson's work carries very little biologic and no geologic significance. His comparisons were made with recent forms only, and as a consequence of his omission of reference to fossil species his work serves, as he states, (p. 186) simply as "a catalogue of the genera found in the collection, with descriptions of part of the species." Although most of his descriptions are good, the small number of figured specimens made his work difficult to deal with until his collection was loaned by the Peabody Museum.

Between 1870 and 1899 nothing was published on the geology and paleontology of the area. In the latter year Josef Grzybowski,³ then an assistant in the Geological Institute of Cracow, published the first account of the geology of the region. With his geologic data Grzybowski included a study of mollusks collected by him, of which he described 35 species from the Zorritos formation, 14 of gastropods and 21 of pelecypods. It should be noted that the fossiliferous beds designated by Grzybowski as Heath have been proven to be Zorritos in age; the fossils catalogued by Grzybowski as Heath are thus Zorritos. Fuller treatment of that matter will be offered in the discussion of the stratigraphy. The interesting fact that of Grzybowski's 35 species only two were recognized by him as identical with species described by Nelson, and that the present work, with the advantage of Nelson's collection, shows only 6 species to be

³ Die Tertiärablagerungen des nördlichen Peru und ihre Molluskenfauna, Neues Jahrb., Beil. Bd. 12, pp. 610-664, pls. 15-20, 1899.

common to the two collections, indicates that the two collectors probably worked in different localities.

Grzybowski's account contained the sum total of data available at the time Van Holst and Singewald began their work. The complexity of the regional structure is too great, and the stratigraphic relationships are consequently too deceiving to permit the obtaining of accurate results in the short time spent at geologic observation by Grzybowski, and it is not surprising to find that his deductions concerning the Heath and Zorritos formations are frequently erroneous. According to Singewald⁴ the fossiliferous beds named as Heath by Grzybowski are part of the Variegated formation, the median member of the Zorritos formation, and the correlation of its few fossils could not be clear with that misconception as to its stratigraphic position in the way.

GEOLOGY OF THE ZORRITOS DISTRICT.

The coastal region of northern Peru is desert from the Gulf of Guayaquil southward to the Morrope valley, a distance of about 200 miles. The coast is fronted as a rule by barren cliffs which are broken here and there by quebradas, or narrow valleys, which extend inland; where sandstone is the underlying rock the cliffs are prominent, and where shales occur there are no cliffs. The region behind the cliffs is of bare hills, which extend in continuous succession from the coast to the Cordillera d'Amotape, a coast range about 2000 feet in average height, about 35 miles from the Pacific Ocean in the latitude of Zorritos, and much nearer to the coast in the vicinity of Negritos. In the vicinity of Payta the country inland is more or less even, consisting of a sandy plateau, but to the north of Cabo Blanco it is rough, and sharp hills and narrow quebradas break the surface into an irregular, inaccessible region. The rainfall is practically nothing, and the only signs of

⁴ Singewald, J. T., Jr., personal communication.

vegetation are those in the larger stream-courses, where small amounts of water support meager plant growth.

The region from which the fossils described in this paper were collected is in the vicinity of the town of Zorritos, extending about ten miles north and south along the coast, and varying distances inland. It is underlain by a series of Tertiary sediments which have long excited commercial interest on account of the petroleum they contain, but which have received scant attention of scientific nature. Oil wells near Zorritos have been productive since 1880, but the location of drilling sites has been almost entirely according to "wild-cat" methods, and not until recent years has geologic work of any kind been applied to commercial purpose.

The first study of the geology of the Zorritos region was published by Grzybowski⁵ in 1899, as the results of observations made during the course of a trip along the coast north of Payta. He differentiated five formations, from highest to lowest as follows:

<i>Age</i> (<i>according to</i> <i>Grzybowski</i>)	<i>Formation</i>	<i>Character</i>
Pliocene	Payta	Conglomerates
Upper Miocene	Talara	Brown shales
Lower Miocene	Zorritos	Sandstones
Lower Miocene	Heath	Bituminous shales
Obligocene	Ovibio	Massive sandstones

The ages assigned by Grzybowski to the formations were determined through the study of rather small collections of fossils. The amount of material was too small in most cases to permit the drawing of valuable conclusions, and in

⁵ Loc. cit.

some cases, as will be seen later, his error in the determination of stratigraphic units led to erroneous results. It is apparent in some instances that he mixed his faunas, including in his collections species undoubtedly not indigenous to the formations from which he was collecting.

Previous to the work done by van Holst and Singewald nothing further was published on the Zorritos region. Their work, done during the winter of 1919-1920, was of highly detailed order, covering thoroughly the area indicated above, and extending well inland. The geologic structure of the Zorritos country is so highly complex that nothing short of very painstaking detailed work may be expected to yield results, and superficial examination is almost certain to lead to misconceptions, particularly if the worker confines himself to the exposures along the coast.

As a result of their investigation van Holst and Singewald differentiated the section which is reproduced in figure 1. The units there presented will be discussed in downward succession.

The Payta and Talara formations do not occur in the region from which van Holst and Singewald collected. The Talara beds appear at the southern end of the area, at Piedras Redondas, consisting there of tan gypsiferous shales similar in appearance to the sandy phase of the Heath formation. No fossils were collected from these beds. Elsewhere in the Zorritos district, that is, within a radius of ten miles along the coast, with Zorritos at the center, the Talara beds do not appear.

Grzybowski's Zorritos formation is the same as that outlined by van Holst and Singewald, with the exception that he confused the Variegated beds with the Heath, and did not recognize the upper and lower sandstone members of the formation. It is perhaps best, in order to make clear the necessary revision of Grzybowski's sections, to quote for reference the critical parts of his presentation.

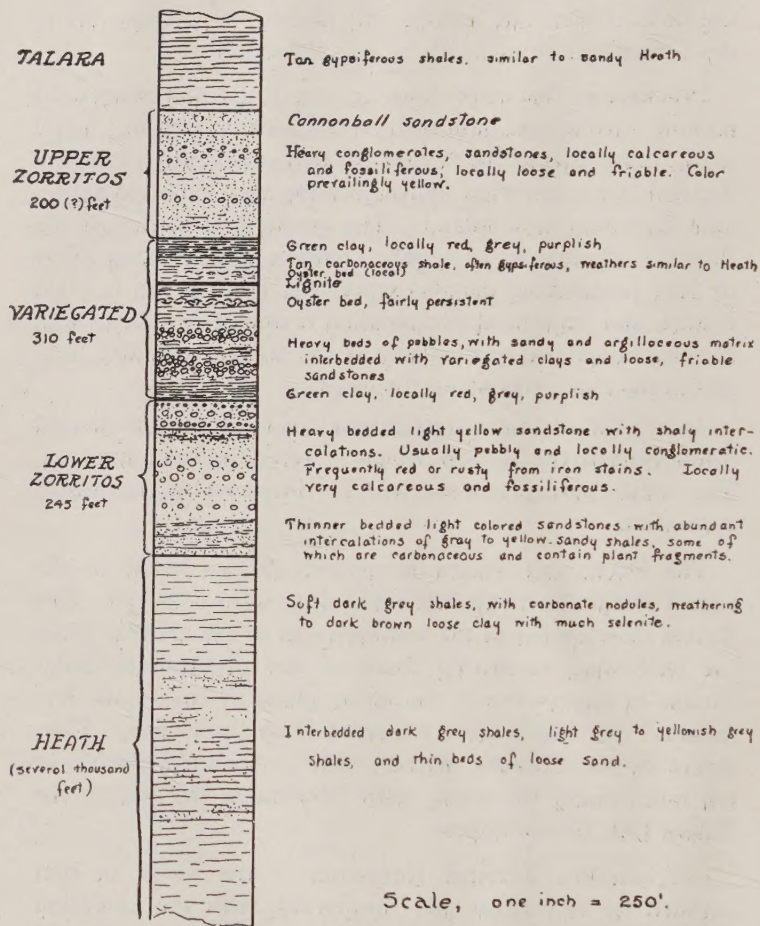


Fig. 1.—Section of the Tertiary of the Zorritos district.

At Malpaso, near Caleta Grau, north of Zorritos, he measured the following section:⁶

- (a) Conglomerate, die zuweilen Rollstücke über Faustgrösse enthalten und viel versteinertes Holz führen. Sie nehmen die höchsten Punkte des bis 150 m hohen Hügelzuges ein.
- (b) Sandsteine, mittelnüch, graugefärbt, bis 40 m mächtig, die bei Malpaso ganz gut zu beobachten sind, da sie hier das Meeresniveau erreichen. Sie sind grabbankig und enthalten senkrecht zu den Schichtflächen stehende, bis 4 dm lange, meist rötlich gefärbte, öfters verzweigte Cylindriten.
- (c) Feinkörnige, dunkle, harte Sandsteine mit Zwischenlagen von dunkel graune Schieferen, bis 10 m mächtig.
- (d) Rothe Schiefer, bis 12 m mächtig; sie sind an manchen Orten durch graue oder grünliche Schiefer vertreten.
- (e) Schwarze, glänzende Schieferthone mit Spuren von Pflanzen, 2 m mächtig.
- (f) Lignit, blätterig, schwarz, viel Thon enthaltend, 80 cm. bis 1 m mächtig.
- (g) Braune Schiefer, bituminös, mit Pflanzenspuren
- (h) Austernbank von 80 cm. Mächtigkeit.
- (i) Bituminöse Schiefer mit Gyps.

Beds a to c, inclusive, of this section, belong to the Upper Zorritos formation, and were considered as Zorritos by Grzybowski. Beds d to i, however, belong to the Variegated formation; they were considered as Heath by Grzybowski, who misinterpreted them on account of the lithologic similarity of the bituminous shales (units e, g, and i) with those of the Heath formation. The shales of the

⁶ Loc. cit.

two formations are identical in appearance either fresh or weathered, and thus offer every opportunity for confusion; the shale of the Variegated, however, is always characterized by the presence of lignite (unit f) and one or two oyster beds above and below the lignite, of which the lower one is fairly persistent, and the other is more or less local in occurrence. Such beds are not known to occur in the upper Heath. The identity of the Variegated beds has been proven beyond doubt through observation of its lower contact with the underlying Lower Zorritos formation, and the position of the Lower Zorritos in turn has been determined through tracing it as an unbroken unit to its contact with the underlying Heath.

It is thus clear that the beds at Malpaso assigned to the Heath by Grzybowski are Variegated, and that accordingly the fossils collected by him from that locality, on the basis of which he determined the age of his Heath, are not Heath, but Zorritos in age. The true Heath formation is not known to bear a molluscan fauna within the Zorritos region. The assignment of Lower Miocene as the age⁷ of the Heath formation is not certain; in the present state of knowledge nothing can be said concerning its age further than the obvious inference that it is older than the Lower Zorritos formation.

A collection of fossil plants obtained from the Zorritos district in 1875 by C. F. Winslow has been described by Professor Edward W. Berry,⁸ who considered the beds that contain them of Burdigalian age. Mention of this conclusion is pertinent at this point on account of the change in its application resulting from the recognition of the Variegated beds at Malpaso, from which general locality the plants were collected. Professor Berry based his stratigraph-

⁷ Loc. cit., p. 658.

⁸ Proc. U. S. Nat. Mus., vol. 55, No. 2270, pp. 279-294, pls. 14-17, 1919.

ic allocation of the plant horizon on the locality, which was given by the collector as 20 miles south of Tumbes, and 200 to 300 feet from the ocean. This is undoubtedly the locality north of Caleta Grau described by Grzybowski, the bed of lignite there being the only one known in any of the formations occurring in the neighborhood, and the location otherwise agreeing with the account given by Mr. Winslow. It should be noted that the evidence of the plants bears upon the upper Variegated formation instead of the Heath, as stated by Professor Berry in accordance with Grzybowski's determination of the beds.

That point clear, discussion of the section as recently determined may be continued from the point at which it was left. The Upper Zorritos formation consists at the top of a yellowish concretionary sandstone, called by van Holst and Singewald the "cannonball" sandstone on account of the characteristic weathering out of the concretions in cliffs. This peculiarity of the sandstone suggested the name of Piedras Redondas, at which place it occurs prominently in the headlands, and at some points it forms cliffs whose erosion form is recognizable for miles. The "cannonball" sandstone underlies the Talara beds at Piedras Redondas. Underlying the "cannonball" is a series of massive beds, in part heavy conglomerates, and in part sandstones which are locally calcareous, bearing fossils and often petrified wood. Yellow is the prevailing color. The Upper Zorritos molluscs later discussed in detail were obtained from these beds. The base of this series consists of very friable sandstones which weather into a yellow sand.

Directly underlying the yellow friable sandstones are the beds d—i of Grzybowski, which form the upper part of the Variegated formation. The highest of these are green clays, locally red, gray, and purplish, the varicolored assemblage of which suggested the name of the formation. Below these clays are the carbonaceous Heath-like shales, oyster beds

and lignite mentioned in connection with Grzybowski's section. Beneath bed i of his section are heavy pebble beds, conglomerates, loose, friable sandstones, intercalated with highly colored clays similar to the uppermost bed of the formation. These brightly colored clays form the base of the Variegated formation.

The Lower Zorritos formation, which follows the Variegated in downward succession, consists above of heavy, massive, in places conglomeratic sandstones, normally light yellow in color, but frequently stained red or brown by iron. The lower part of the formation is locally very calcareous and fossiliferous; most of the molluscs hereinafter described from the Lower Zorritos came from these lower horizons. The basal Lower Zorritos sandstones are thin-bedded, with abundant intercalations of gray to yellow sandy shales, some of which are carbonaceous and contain plant fragments.

The Heath formation, the lowest exposed in the district, consists primarily of gray shales, which weather brown, with light gray to yellowish gray sandy shales and thin beds of loose, unconsolidated sands interbedded with dark gray shales. The uppermost beds are the soft dark gray shales, with carbonate nodules; they contain much selenite and weather to the characteristic reddish brown color, excepting the vicinity of Sechurita and in Quebrada del Grillo, where they weather to a pale green. Below the upper shaly beds the sandy phase appears; it consists of a thin-bedded alternation of very loose and unconsolidated sands with clays lighter in color than those mentioned above. At and south of Quebrada del Grillo the sandy horizon is represented by a bed of heavy conglomerate. The entire Heath series is measurable in thousands of feet; its thickness is unknown, the base not having been seen, but several thousand feet of it have been observed on the coast south of Zorritos. The Heath is the mother-rock of the petroleum mined in the Zorritos region, and most of the notable production is obtained from horizons in its sandy phase. The Zorritos

formation yields oil in places; but the source is undoubtedly the Heath formation.

Faulting rather than folding characterizes the structure of the region, most of which consists of a series of tilted fault-blocks. There are several lines of major faulting, the direction of which is a bit more northerly than that of the coast line, parallel to which the fault-blocks are usually tilted inland. In addition there are countless transverse faults which break the region up into a veritable mosaic. The general result is, ordinarily, that the Heath formation is exposed at the base of the major blocks, with either the Upper Zorritos or the Lower Zorritos at the summit, the series dipping inland until it is interrupted by the next longitudinal fault, or crossed by a diagonally transverse fault. About Boca Pan the whole series is broken up into very small blocks, and the structure is unusually intricate.

The sections exposed along the coast, where the cliffs parallel, roughly, the lines of major faulting, give small hint of the actual structural complexity of the region, and, with the exception of points at which transverse faults break the series, the beds appear to dip in continuous succession, undulations bringing the various members to light and carrying them under again. The impression obtained from Grzybowski, who saw little more than the coastal exposures, is rather that there is no great complexity. The recent study has brought out the true nature of the structure as indicated above. Grzybowski's idea that no great structural difficulties existed was undoubtedly the reason for his failure to recognize the separate entity of the Variegated beds.

At a point not far north of Caleta Grau the Heath beds are faulted against the Variegated on the line of one of the transverse faults. The similarity in lithology of the two beds might lead a hurried worker to miss the fault; however, on the ridge north of Caleta Grau the Lower Zorritos formation is seen to overlies the Heath, and the contact between the two may be clearly traced to the point at which

it is cut off by the transverse fault mentioned, and the Lower Zorritos is juxtaposed to the Variegated. From the ridge at the point where the three formations meet, the whole situation is clear.

The principal drainage of the region is determined by the fault-lines, and the rough physiographic aspect of the terrane is due to the irregular disposition of the fault-blocks, which form the hills between the drainage channels.

ANALYSIS OF THE FAUNA.

I—GENERAL CONSIDERATIONS.

An analysis of the collection here studied, made from either the biologic or the geologic viewpoint, can present evidence of positive nature almost exclusively. It is almost certain that enough of the entire Zorritos fauna is as yet unknown to forbid the drawing of conclusions based on the absence of any element, and although much can be deduced from the presence of those forms now known, the satisfying completeness of a study which includes all inferences, positive and negative, must be foregone until highly detailed collecting either furnishes elements yet to be known or proves that the majority of the species are embodied in the present study. In the case of the Upper Zorritos formation it is not certain that a very large fauna exists, although it is probable that considerable additions may be made through protracted search for new localities, but both the Variegated and the Lower Zorritos formation give promise, through a multitude of indeterminate fragments in the matrix of the present collection, of a fauna which may approach in richness some of the famed Antillean and Floridian assemblages of approximately similar age.

One difficulty which must be solved before the study of these faunas can be completed is the procuring of good material. This applies in particular to the minute and more delicate species. The matrix in which most of the specimens

so far collected occur is far too resistant to permit the extraction by any known means of specimens at all susceptible to injury through moderate violence; the sands are firmly cemented by calcium carbonate, and attempts at removal of matrix by loosening it through chemical destruction of the cement fail because the shell material is of the same composition, and is destroyed along with the matrix. Loose matrix on some of the specimens in the Nelson collection indicates that there are probably some localities at which the sands have not been cemented, and with the discovery of such places a large fauna may be revealed to the paleontologist.

II—BIOLOGIC ANALYSIS.

The present study has made known 101 species and varieties of mollusks, of which 44 are gastropods and 57 pelecypods. Two of the species are indeterminate and 64 are new. 31 occur in the Upper Zorritos formation, 15 in the Variegated, 43 in the Lower Zorritos, and 20 from Nelson's collection do not occur in the material collected by Singewald, and are thus not stratigraphically located beyond the high probability that they came from the Zorritos formation.

The gastropods are somewhat widely distributed through the biologic scheme, most of the 18 genera being represented by one or two species, and only two genera, *Conus* and *Turritella*, being represented by more. In the case of the Cones this is not surprising, since the normal tropical fauna contains a heavy representation of that genus. The Turritellas, however, are not ordinarily diversified in the tropics to the extent found in the Zorritos fauna, and the seventeen species and varieties here presented seem entirely out of proportion with the rest of the fauna. Accidents of collecting might explain the relatively more complete assemblage of the genus, and thus relieve the disproportionate aspect of the group, but granted that, the number is still larger than one

would expect. The recent Peruvian littoral fauna contains four species of *Turritella*. Maury⁹ lists but three species out of the 451 discussed by her from Santo Domingo; the rich Bowden fauna contains but two species; the Chipola fauna contains six species and varieties;¹⁰ the Oak Grove two;¹¹ the Tampa silex beds five species and varieties.¹² The only American tropical fauna which approaches the Zorritos in mere number of *Turritellas* is the extremely rich Calloosahatchie assemblage, which contains 12 species and varieties. It is worthy of note that of the twelve, seven are peculiar to the deeper water faunule of the Calloosahatchie River locality, and all occur there; two more are peculiar to that locality and the Shell Creek, which offers a facies shallower, though probably still deep, and thus at least cooler water. It is thus probable that all of these species are deeper water forms. The other Pliocene faunas are poor in *Turritellas*; the Waccamaw contains but one. The Duplin Miocene, a warm-water fauna, contains about nine or ten species and varieties, all of which are very much alike.

In face of comparative data such as these the occurrence of so varied and extensive a development of the genus in a fauna, the data on which are by no means complete, is at least interesting. Analysis of such scattered data on the habitat of the genus as are available shows that *Turritella* seems to prefer comparatively deep water; however, nothing definite can be said on that question, since published data conflict to large extent, and there is thus no certainty. It is difficult, in the absence of even a little reliable ecologic information, to say whether or not the abundance of the *Turritellas* in the Zorritos fauna means a deep-water origin of the beds enclosing them. The evidence of the lithology,

⁹ Bull. Amer. Pal., vol. 5, No. 29, pp. 129-130, 1917.

¹⁰ Dall, W. H., Trans. Wag. Inst., vol. 3, pt. 6, p. 1577, 1903.

¹¹ Ibid., p. 1590.

¹² Ibid., p. 1567.

as well as that of the other species, seems to demand a strictly littoral zone as the habitat of most of the fauna. Most of the Upper Zorritos *Turritellas*, for example, occur at Quebrada del Toro, in a sandy matrix which does not bespeak deep water bottom conditions.

It is possible, however, that those horizons which are notable for the larger, more diversified *Turritellas*, chiefly of the Upper Zorritos formation, may represent at least temporary occurrence of deep-water conditions. If that is the case, the coast must have had a declivity sharp enough to permit the carrying of somewhat coarse materials out into deep water, and the run-off must have been at least locally strong enough to wash sands and small pebbles some distance beyond the strand. It is entirely possible that periods of flood on a steeply sloping coast may have carried the coarse material found with many of the Upper Zorritos fossils into comparatively deep water.

The presence of a *Triumphis* in the collection is of interest in that the genus, as now recognized, contains but one other species, and that living, restricted to the West Coast. The Zorritos species is apparently the first of its direct ancestors to be known. It is highly probable that a comparative study of the genus *Agasoma* Gabb will show a relationship to *Triumphis* closer than that now expressed, with the possibility that *Agasoma* may have to go into synonymy. In the latter event the genus will have a broader range, with more fossil species.

The remaining gastropods are almost uniformly of groups naturally to be expected in a tropical American Miocene fauna, and the chief interest they offer lies in their geologic affinities. One species of *Solenosteira* is interesting in that it is of a type not widely known from the Miocene, but developed to some degree in the recent fauna of the West Coast. A single species from Gatun is the only other known in the Miocene. The ancestors of the recent forms are thus found in the Panamanian—Peruvian region. Other fossil

species, notably from the Floridian Tertiary, are differently developed.

Phos latirugatus represents a type which is apparently little developed anywhere in known faunas; most of the *Photinae* have more rounded, less sharply carinate whorls, and members of the type here found, with a distinct shoulder, are not common.

The pelecypods offer somewhat more widely distributed diversity than do the gastropods, although they, too, are unbalanced on account of their incompleteness, as a result of which statistical biologic discussion can enter into few features with profit. The species are distributed through 20 genera and 13 families. The Taxodonts are an important element, being represented by 20 species and varieties, of which 19 are of the genus *Arca*. These 19 species and varieties, distributed through 4 subgenera and sections, are the most brilliant and prolific, if not the most interesting of the Zorritos pelecypods. The Lower Zorritos group is characterized by smaller species, and the Upper Zorritos and Variegated by larger, heavier forms. The closely related groups have been difficult to separate satisfactorily, and the author is fully conscious of the fact that others may view the present treatment with thoughts of revision; however, the grouping here offered is believed to be the most rational according to the more or less unexpressed limitations of morphologic differentiation, and the amount of material available for use in discriminating some of the more troublesome species has been sufficient to give the author some measure of confidence in his decisions.

It is apparent that the Zorritos region, as well as the Antilles and Florida, was the scene of the divergence of the Cunearcas from the true Scapharcas; the presence of three species, *Arca larkinii* Nelson, *Arca pantheonensis* n. sp., and *Arca zorritensis* n. sp., very near the border-line between the groups, each exhibiting some feature either somewhat anomalous to the preponderance of other sectional char-

acters, or indicative of progressive change from one type to the other, offers further evidence of the transition between the sections, and adds to the list of illustrations which show the completeness of the gradation between them.

The presence of the subgenus *Noëtia* is of interest in its addition to the Miocene occurrence of that group, which is distinctively American in fossil distribution. Grzybowski described a species, *A. (Noëtia) modesta*, from Zorritos which is apparently different from *Arca cholana*, and another unstudied *Noëtia* occurs in a collection of stratigraphically unlocated fossils from Peru which, by inference from the locality labels, may have come from the Zorritos formation. The absence of the subgenus *Arca* s. s., an element normally to be expected in a fauna such as this, means little as yet.

The one *Pecten*, *P. woodringi*, is of the small, tropical type. *Anomia berryi* is interesting on account of its size and weight; the Upper Zorritos and Variegated habitats at which this species has been found must have been peculiarly favorable.

One of the striking characteristics of the Lower Zorritos faunule from Quebrada Zapotal is the abundance of *Cras-satellites berryi* n. sp., a distinctive type, undoubtedly representing a peculiar divergence from the ancestral strain of *C. gibbosus* Sowerby, now living on the Peruvian coast. *C. nelsoni* (Grzybowski) probably represents the stock which preceded *C. gibbosus* in direct genetic line.

The occurrence of *Clementia dariena* Conrad, a member of a genus with sparse fossil and not much wider recent distribution, is worthy of note. This species is known so far only from Panama, Costa Rica and Peru, and its clear identity makes it a conspicuous element, despite the fact that it is not known to be abundant. It is unfortunate that the stratigraphically located specimens of *C. dariena* in the present collection are not well preserved, the ones in the

uncertainly located Nelson collection, being in very good condition, having served best for morphologic study; the poorer material gives hints of some variations both in size and form which may deserve systematic recognition, but not enough can be substantiated to make distinctions. The *Dosiniinae* of the collection are further characterized by the occurrence of a large, heavy form, *Dosinia grandis* Nelson, very much like *D. orbicularis* Agassiz, of the European Miocene.

Perhaps the most interesting single occurrence in the pelecypod fauna is that of *Amiantis incrassata* var *ovoidalis* Sacco, a variety common in the Tongrien of Europe, and of a genus very rare in known American faunas. It is hardly possible, in view of the several variations of *A. incrassata* in Europe, that this particular variety reached Peru as a direct migrant from the central European seas, and the apparent absence of the species in well known faunas occurring along possible lines of migration and at the same general time horizon lends strength to that assumption. It seems far more likely that parallel development may account for the evolution of characters in the Peruvian form exactly similar to these of the European *incrassata*.

The Raëtas are always an interesting element, and the Zorritos fauna, with three well-defined yet closely related species, presents some unusual developments in that group. *Labiosa* (*Raëta*) *gardnerae* occurs in great profusion in the Upper Zorritos sandstone at Quebrada de las Alturas, and one specimen has been found in the Lower Zorritos. *L. ventricosa* is a short, inflated shell unlike any known fossil *Raëta*, and of very interesting aspect. Some of these small fossil Raëtas show affinity to the section *Raëtina* Dall,¹³ of recent Indo-Pacific distribution, but they all show evidence of the posterior lateral tooth, the absence of which is a

¹³ Trans., Wag. Inst., vol. 3, pt. 5, p. 882, 1898.

sectional characteristic of *Raëtina*. They are smaller in size than the usual Miocene Raëtas.

The Corbulas of the section *Aloidis* present transitions between other similar forms from Antillean horizons, features which are brought out in the systematic discussion of the group. This genus, with six species, in two sections, stands next to the Arcas in point of specific diversity. *Corbula* (*Cuneocorbula*) *acutirostra* n. sp. is a sharply defined species with an unusually marked development of the posterior keel, and is most closely related to two species from the Oligocene of Germany.

A rapid survey of the faunal list confirms the natural expectancy of finding a tropical facies, and it is hardly worth while to use space for detailed discussion of that point. Almost all of the genera thus far described from the region are characteristic of the tropical seas, and none is extraneous to such a habitat. It is true that some of the types have been found in cooler-water faunas, but such have a wider range, and their presence in this fauna introduces no discordant element.

The preponderance of ecologic evidence offered by the fauna, and supported by the type of sediments in which they were entombed, indicates a shallow water habitat as the rule. All of the species are of genera now living in the littoral zone, most of them present in the recent fauna of that zone on the Peruvian coast, an excellent list of which has been published by Dall.¹⁴ Some of the matrix verges on the conglomeratic in character, containing pebbles of the sort one would expect to find in somewhat agitated waters, and hardly in the quiet of the usual off-shore bottom. Most of the species, however, occur in sediments distinctly of the sandy littoral type, and it is fairly certain that the fauna flourished, for the most part, in that zone.

¹⁴Proc. U. S. Nat. Mus., vol. 37, No. 1704, pp. 147-294, pls. 20-28, 1909.

In the systematic presentation of this fauna the author has endeavored to supply accurate references to all forms discussed. These references are to original descriptions in all cases excepting those in which subsequent treatment is better either through superiority of figures or greater completeness of description. References have been made to all species with which comparison is pertinent, and although it may seem to some that too large a number of similar forms has been quoted in the remarks on some of the species, the writer has included such as are presented out of first-hand knowledge of the assistance they render to students of similar faunas. Paleontologic work as a whole is characterized by too great brevity of treatment in matters of detail and comparison—brevity at the expense of efficiency on the part of those who find need later to use the work; and it is certainly for the benefit of such, in greatest measure, that details are mentioned at all.

III—GEOLOGIC ANALYSIS.

The determination of the age of a fauna, and particularly one from a region somewhat distant from the nearest well known locality, ordinarily involves a number of uncertainties which make advisable, if not necessary, the obtaining of complete data before valuable conclusions may be drawn. This is particularly true of faunas which show affinities sufficiently scattered to cause careful weighing of all evidence, and since many fossil assemblages are of such character an attempt at correlating a fraction of a fauna, if advisable, should be accompanied by some statement as to the degree of faith to be placed in the results. It may be said in behalf of the present study that the affinities of the Zorritos fauna, and particularly that of the Lower Zorritos formation, are so strongly centralized that the discovery of the numerous additional species which no doubt exist may confidently be expected to confirm the present deductions, and under no circumstances to change the character of the evidence

beyond the possible introduction of a few exotic or otherwise interesting relationships.

The treatment of a fractional fauna such as that here considered is more a matter of judgment than of tabulation and derivation of percentages. The system of expressing faunal relationships through percentages is faulty under the best circumstances if the specific determinations or the alignment of affinities is at all loose, and so much variation is encountered in both of these matters that the evidence of a group of species needs to be tempered by a differential weighing of the strength of individual determinations and the degree of closeness in relationship shown by separate forms. Could systematic paleontology be standardized the student would be freed of the necessity for examining closely the results obtained by others, but the element centering about the personal equation is inevitable in its effect on the character of a study, and the student must take separate account of determinations if his work is to be balanced. So much depends on the drawing of specific lines that a work in which it is necessary to make close distinctions is sure to reflect more the character of the worker than that of the fauna in matters which hinge on minute determinations. And it is obvious that anything verging on predisposition is dangerous.

Although in the present work the major elements will be expressed in the form of percentages, their value must be considered to lie in the preponderance of affinity they reveal rather than in any intrinsic quality of the figures themselves. It is obvious that the smaller relationships, such as those with the recent faunas, can not bear much weight for two reasons which hinge on the size of the fauna: first, the incompleteness of the assemblage makes an attempt at expressing proportions probably false, and second, the percentages obtained in dealing with smaller total numbers of fossils are out of proportion with the ideas the numbers should actually express. In a group of forty species two

represent five per cent; if collecting were sure to have been strictly representative such figures might bear weight, but such is rarely the case, and is not recognizable if it does occur. It is obvious that the determination of affinities in the case of a small fauna of doubtful or heterogeneous aspect is attended by danger, and it is fortunate for the results of the present study that the affinities of the Zorritos fauna are strong enough to leave no doubt as to its age relative to the known Antillean faunas, and little or no doubt as to its position in the standard European time-scale.

The accurate determination of the horizons from which the fossils were taken offered a first-hand opportunity for the discernment of differences in the faunal characteristics of the three members of the Zorritos formation, and in view of the superficially different appearance of the fossils the work was begun in anticipation of the discovery of faunal zones, possibly of distinctly different ages. As will be seen when the three faunas are taken up in detail, such difference is by no means marked, and although the Upper Zorritos may to some degree be differentiated from the Lower Zorritos in age, the difference between the two faunas is probably more one of facies than of time. The Variegated faunule is too small to permit the drawing of conclusions further than to indicate its relationship to the neighboring beds.

Six of the eighty-one species are common to the Upper Zorritos and the Variegated; two are common to the Lower Zorritos and the Variegated; four are common to the Upper and Lower Zorritos, and a number of species from the Lower Zorritos formation have close relatives in the Upper Zorritos. These figures lead to the observation that in point of common species the Variegated faunule is more closely related to the Upper Zorritos than to the Lower Zorritos, but the incompleteness of the Variegated faunule leaves too many possibilities open to permit serious consideration of that.

There is, however, apparently a difference in facies be-

tween the faunules of the Upper and Lower Zorritos formations which may well prove constant in face of further collecting, and may thus serve as a valuable guide to the recognition of the units where fossils are found and there is doubt, owing to structural complexities, as to the identity of the beds. This difference appears most clearly expressed in the Arcas and the Turritellas, because of the abundance of those forms and their marked difference in facies. The Arcas of the Upper Zorritos formation, as has been noted, are larger, heavier shells than those of the Lower Zorritos, and a similar difference occurs in the Turritellas. Separate species of other single genera do not occur in both formations, as far as the present collection shows.

The difference in the Arcas may be an index to a greater time difference between the Upper and Lower Zorritos formations than the general affinities now apparent seem to demand. The Arcas of the Upper Zorritos appear to be of a later type, some of them closely related to *A. idonea* Conrad, a species which is most abundant in the Chesapeake Miocene, in beds of Tortonien age. Others are close to *A. grandis* Broderip and Sowerby, and *A. tuberculosa* Sowerby, both more modern types. *Cerithium Grillanum* n. sp. is very close to *C. russelli* Maury, from the Helvetien of Santo Domingo, and two of the Turritellas, *T. nelsoni* and its variety *rotundata* are close to species from the Helvetien of Europe.

These later affinities, despite the fact that they are overshadowed in present number by the strictly Burdigalien affinities, promise a greater possibility of finding more evidence of their kind than there is for the Lower Zorritos faunule, which in its larger number contains a proportionally much smaller Helvetien and Tortonien element. Thus, although it is not possible to say that the Upper Zorritos is very much younger than the Lower Zorritos, it is advisable to indicate the definite possibility that future work may reveal a Helvetien element sufficiently strong to necessitate considering the fauna of that age. In the present state of

knowledge it appears to be later Burdigalien in age. Such a difference between the Upper and Lower Zorritos formations is not irrational to suppose when we consider that the Variegated formation, with its continental beds, may contain a hiatus of considerable magnitude.

As might be expected, the fauna as a whole has its nearest relatives in the general region between Panama and Florida. The alternative anticipation would be to look for affinities in the Tertiary of Chile, Patagonia, and New Zealand, and although in rare cases such occur, they are not suggestive of any well-defined connection between the faunas of the two regions. Grzybowski noted the presence of affinities with the Navidad and Coquimbo beds of Chile, five of the sixteen species in his Heath (=Variegated) faunule being identical with or closely related to Chilean species. These five species are all in his list from the locality north of Caleta Grau, near Malpaso, at which he was unquestionably dealing with the Variegated formation. No such species has appeared in the Hopkins collection, and very few which show any affinity to Chilean species. Grzybowski noted no Chilean element in his Zorritos fauna, which is equivalent indiscriminately to the present Upper and Lower Zorritos. He did, however, note a Chilean element in his Payta fauna.

It is probable that at least during the periods of the Upper and Lower Zorritos formations connection with the southern coast was cut off. A point of land similar to that about Point Aguja and Gabo Blanco, which now diverts the colder Humboldt current seaward, and marks the northern limit of the Peruvian Province, probably existed farther to the south during part of Miocene time, giving rise to conditions similar to those now existing, but with the southern limit of the purely tropical littoral, corresponding to the present Panamic Province, farther south. The location of such a point at the various stages of the Tertiary will be known when the coastal geology and paleontology have been studied in greater detail and over the entire area.

This postulate demands a distribution of marine currents and temperatures, and thus marine animals, somewhat different from that existing today. In a study of the recent littoral molluscan fauna of the coast of Peru Dall found that the Magellanian element in the fauna is the most conspicuous, despite the fact that many of the species are common to the Panamic Province, and that accordingly the fauna seems to be largely of southern origin. Since the beginning of Tertiary time conditions have probably vacillated somewhat, with the north Peruvian coast as the scene of change from colder-water, Magellanic faunas to tropical, Antillean-Panamic faunas as changes in the coast line varied the point of divergence of the southern, now called the Humboldt current. Temperature conditions seem to be the chief governing factor in the constituency of a littoral molluscan fauna.

It is possible that during Variegated time there was a reversion from the purely tropical conditions of the Lower Zorritos to conditions under which the colder currents again had access to the north Peruvian coast, and the Chilean element noted by Grzybowski may thus be accounted for. Two things, however, alter the clearness of such a postulate: first, the existence of the Chilean forms in the Variegated has not been checked, and second, it is the opinion of some observers of South American geology that a considerable land mass existed during Miocene time to the west of the present coast and in the general region south of central Peru; a slight change in the course of ocean currents such as that called upon to explain the Chilean element in the Variegated depends on coastal conditions essentially similar to those now existing, and the presence of a considerable projecting land mass to the south would have eliminated the colder water entirely from the Peruvian region. The existence of such a land mass, however, is far from proven, and the presence of Chilean types in the Variegated beds needs to be explained. A shifting of the point of land which

caused the diversion of the southern current might well have allowed the Chilean forms access to the north Peruvian waters during Variegated time.

Ortmann,¹⁵ in discussing the possibility of a separation of South America into two masses according to the "Archhellenis—Archiplata" theory of von Ihering, points out the dissimilarity of the north Peruvian faunas from those of Navidad, Chile, and Patagonia in support of the hypothetical central seaway as a barrier to the intermingling of the regional faunas. It does not seem necessary to presuppose so vast a change as the splitting apart of South America in order to explain the difference between faunules which by virtue of their location alone might be expected to differ. All data so far collected indicate that there is unbroken structural and geologic continuity along the Andean axis from Panama to the Straits of Magellan. The existence of north-south lines of tectonic weakness is established both through the immense Andean uplift and the sunken blocks which have given rise to the famous deeps off the west coast, and it is extremely unlikely that a major line of weakness existed in comparatively recent times at right angles to these known. The sea separating "Archhellenis" and "Archiplata" would have had to be deep enough to prevent the migration of molluscs, and broad enough to forbid the passage of free-swimming larvae. Evidence of so great a break in the continental mass of western South America, which should be discernible if the seaway existed, apparently is not present, the general geologic situation on the west coast suggesting complete continuity, with no hint of a break.¹⁶ There may have been, and probably was a profound embayment of the Amazon basin, but submergence of the site of the Andes is not evident from observations thus

¹⁵ Princet. Exp. Patag., vol. 4, p. 298, 1901; also pp. 319-324.

¹⁶ See Berry, E. W., Geol. Soc. Am. Bull., vol. 29, pp. 637-648, 1919; Proc. Pan Pacific Sci. Conf. pp. 845-865, 1921.

far available, and can not be proven through mere dissimilarity of faunas in regions which might have offered different habitats for any one of a number of reasons involving the disposition of coastal land and the distributions of ocean currents, or which might have been faunally isolated from one another for similar reasons.

There is evidence, on the other hand, which is difficult of explanation if a sea-barrier separated two continental masses according to von Ihering. The upper Cretaceous flora of Argentina, according to Kurtz¹⁷ is derived from that of North America. It could hardly have passed the sea-barrier. The Miocene flora of the Navidad beds, Chile shows close affinity to floras of similar age found in Ecuador and Peru, and extremely close relatives of the Navidad plants are living today in the upper Amazon country, in Peru and Bolivia, according to Berry.¹⁸ These facts do not support but contradict the theory of a central seaway.

The remaining part of this discussion will be concerned with the age relations of the fauna. A survey of the table of distribution and affinities, will show at once the relationships of the separate species, and the discussion to follow will embody merely the grouping of the evidence, with remarks on pertinent points and without repetition of faunal lists.

The fauna as a whole, shows affinities so strongly Burdigalian that much discussion is not necessary. The term Burdigalien is used not to indicate that the age determination has been made through European comparisons, but because the European units are more expressive of exact age relationship, and are standard; the fauna is closest to Panamanian-Antillean-Floridian assemblages of well-established Burdigalien age.

¹⁷ Kurtz, F., *Rev. Mus. La Plata*, vol. 10, pp. 43-60, (1899) 1902.

¹⁸ Berry, E. W., personal communication; also *Proc. U. S. Nat. Mus.*, vol. 55, No. 2270, p. 283, 1919.

The following table will show readily the distribution of affinities for the total fauna. The percentages represent those of species either occurring elsewhere or having close relatives elsewhere at the horizons noted.

Restricted to Burdigalian	43%
Occurring in Burdigalian.....	71%
Restricted to Helvetian.....	7%
Tortonian and later.....	11%
Oligocene (chiefly Aquitanian)....	10%
Eocene	5%

It is thus clear, although these figures are really not the most efficient medium of expression, that the fauna is unmistakably Burdigalian in age. Since 87 of the 101 species are peculiar to the Zorritos formation it is practically necessary in attempts at expressing analysis to consider close affinities together with identical occurrences, and inasmuch as such affinities as have been indicated are close enough to warrant such action, the two are not separated in discussions of totals.

This determination confirms Grzybowski's statement of the age of his collections from the same horizons, and it is worthy of note that he obtained his results through comparison with European species, almost to the exclusion of others, at a time when the geology of the Panamanian-Antillean region was little known. He did not place his fossils definitely in the Burdigalian, but stated that they were of Lower Miocene age. A later determination of the age of the Variegated formation, by Berry,¹⁹ depends on fossil plants for its conclusion, and agrees with Grzybowski's results in calling the beds Burdigalian. The results of these observations, diverse in manner of treatment, agree with satisfying precision.

Twenty-two of the 101 species are either closely related to or identical with Gatun species; 29 with Santo Domingan

¹⁹ Proc. U. S. Nat. Mus., vol. 55, No. 2270, pp. 283-284, 1919.

species from the Cercado formation, of Burdigalian age, and 8 with Chipolan species. The remaining Burdigalian affinities are scattered as shown by the table.

Thirteen species either occur at Bowden or have close relatives there. The latest opinion, based on unpublished studies by Dr. W. P. Woodring, of the United States National Museum, is that the Bowden beds are Helvetian in age; however, most of the Bowden forms related to species from Zorritos are of clearly older affinities, and the Zorritos fauna contains few species closely related to that more modern element in the Bowden fauna which indicates its place in a higher stage.

The species which occur elsewhere may be tabulated as follows:

Gatun	5
Santo Domingo (Cercado)	3
Santo Domingo (Gabb)	2
Bowden	5
Atlantic Miocene	2
Chipola Marl	1
European Oligocene	1

The geologic discussion of the fauna will conclude with a brief consideration of each of the constituent four groups.

Upper Zorritos Fauna: The proportions of the Helvetian and Burdigalian elements in the Upper Zorritos fauna have already been discussed in general. Exact tabulation of relationships will be found in Plates 2, 3, and 4; it will suffice to say here, statistically, that in the large Burdigalian element represents about half of the total fauna, with the Helvetian and Tortonien aggregating somewhat less than a third. The Helvetian element is so characteristic and profuse, however, that the numerical expression fails to portray the situation fully. Although present evidence demands consideration of the fauna as Burdigalian along with the Variegated and Lower Zorritos, there is no doubt that it

represents, faunally, a later stage, and that the appearance in further collecting of a reasonable number of more modern species would easily throw the balance toward the Helvetien.

As was noted in the preceding discussion of formational inter-relationships, the Arcas and the Turritellas are the chief distinctive groups of the Upper Zorritos, and although some of the species range into the Variegated, their complete difference in the Lower Zorritos affords one point of distinction between the two formations which may prove of use in field recognition. Other species, such as *Pecten woodringi*, *Conus cacuminatus*, and *Cerithium infranodatum*, of the Upper Zorritos; *Dosinia grandis*, *Corbula propinqua*, and *Macrocallista helenae*, of the Variegated; and a much larger number from the Lower Zorritos appear to be characteristic, and may serve similar purpose; however, they are as a whole not as prominent as the Arcas and Turritellas, and their range is not yet sufficiently well known to make them of high value.

Variegated Fauna: The collection from the Variegated beds, of fifteen species, is too small to permit far-reaching conclusions, but a few observations may be worth while. The preponderance of Burdigalian elements, well over half the total, in the fauna here represented is such as leave small doubt as to the age of the beds, and although the general facies is in some ways similar to that of the Upper Zorritos fauna, the affinities are closer to those of the Lower Zorritos. That fact lends strength to the possibility that the whole formation is of nearly the same age, but it can not mean much at present; future work might easily change the conclusions based on so small a faunule as that now available. There is small doubt, however that the Variegated will prove to be of Burdigalien age.

Grzybowski lists 16 species from the Variegated (his Heath), of which only three occur in the present collection, with none of the three from the Variegated. The remaining

13 species appear to have well-defined lower Miocene affinities, and five of them are apparently of Chilean Miocene types. It is the belief of the writer that the Variegated beds will be shown to contain many more species in common with the Upper and Lower Zorritos formations than are now apparent.

Lower Zorritos Fauna: This fauna presents the most strongly peculiar aspect of all. In addition to the fact, already noted, that it shows very strongly centralized affinities, it has a facies more distinctly peculiar than has either of the other two faunas. The Gatun-Cercado elements are certainly predominant, and the age of the fauna is certainly Burdigalien, at least in the sense of the American stratigraphers. Over half of the Lower Zorritos species are closely related to species restricted to the Burdigalien, and approximately eighty per cent to species occurring in the Burdigalien. The affinities of other elements in the fauna may be seen readily in the tables, plates 2, 3 and 4.

Nelson's Collection: The collection described by Nelson contains a number of species which do not occur in the Hopkins collection. Inasmuch as Messrs. Larkin and Bradley, the collectors, stated that the specimens came from the direct vicinity of Zorritos, in which locality the Zorritos and Heath formations are the only ones exposed, and since the general facies of Nelson's fossils indicates a common origin, they have been assumed to come from the Zorritos formation. It is unfortunate that they have not been located within the limits of that unit, but when considered with the fauna as a whole they contribute interesting additional evidence of the Burdigalian age of the beds. Approximately forty per cent of the species have restricted Burdigalian affinities.

LIFE

Edmund Maute Spieker was born in Baltimore, Maryland, on the twenty-fifth of February, 1895. His earliest education he received at home. He entered the public grammar schools of Baltimore in 1903, and the Baltimore City College in 1908, receiving the diploma of that institution in 1912. He was admitted to the degree of Bachelor of Arts in the Johns Hopkins University in 1916, since which time he has been engaged, with the exceptions noted below, in graduate studies in the department of Geology at Johns Hopkins. He has held Hopkins scholarships during the period of graduate work, and was elected to the Phi Beta Kappa Society in 1921.

During the field season of 1917 he was Geologic Aid in a party of the United States Geological Survey, working in northwestern Montana; from April to August in 1918, as Geologic Aid and Assistant Geologist, he was engaged in work for the Federal Survey in Oklahoma. From August to December, 1918, he was a private in the United States Army, and was discharged from that service at the Coast Artillery Officers' Training School on November 21, 1918. From April to December, inclusive, of 1919, he was engaged in geologic work for the Imperial Oil Company in northwest Canada. During May, 1920, as Associate Geologist, he prepared a digest of oil occurrences in the Near East for the Foreign Mineral Resources branch of the United States Geological Survey. From June to November, 1920, he had charge of geologic investigations south of the Peace River in northern British Columbia for the government of that province.

He is the author of the following papers:

PETROLEUM IN PERSIA AND THE NEAR EAST, *Engineering and Mining Journal*, vol. 110, no. 7, pp. 316-323, 1920.

THE GEOLOGY AND OIL RESOURCES OF THE FOOTHILLS SOUTH OF PEACE RIVER IN NORTHEASTERN BRITISH COLUMBIA, *B. C. Dept. Lands*, Victoria, 1921.

REPORT OF OIL SURVEYS IN THE PEACE RIVER DISTRICT, 1920. *B. C. Dept. Lands*, Victoria, 1921. (with J. A. Dresser)

THE PETROLEUM GEOLOGY OF A PART OF THE WESTERN PEACE RIVER DISTRICT, BRITISH COLUMBIA. *American Association of Petroleum Geologists*. Bulletin vol. 6, no. 2, pp. 112-138, 1922.

